# Legislative aspects

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## 4.1 Introduction

**Guide for the reader: Structure of chapter "4":**

This chapter contains a lot of information on the new European approach to regulate natural radioactivity in building materials.

- The main Directive that deals with natural radioactivity in building materials is the Euratom-Basic Safety Standards Directive (EU-BSS) and its approach to regulate building materials is described in Section 4.3. Some additional information on the link with the Construction Products Regulation (CPR) is provided in Section 4.3.1.
- For the reader who wants to explore the history of the EU-BSS and several important earlier documents in greater depth we refer to Section 4.2.
- For the reader who wonders how the Euratom drinking water Directive might impact on building materials we refer to Section 4.4.
- In Sections 4.5 and 4.6 current national legislations on natural radioactivity in building materials are considered in more detail.
- Several tools are described for the screening of the radiological properties of building materials. These tools are discussed in Section 4.7.

It is well known that, owing to their natural radionuclide content, building materials give the most significant contribution to the indoor gamma dose (UNSCEAR, 2008). This is why for some 30 years researchers have investigated building materials from a radiological point of view and why, more recently, regulators have recognized building materials to be an important issue from the radiation protection (RP) point of view.

The recycling of NORM residues in building materials may be a sustainable option to counteract the further depletion of valuable raw materials. For the evaluation of

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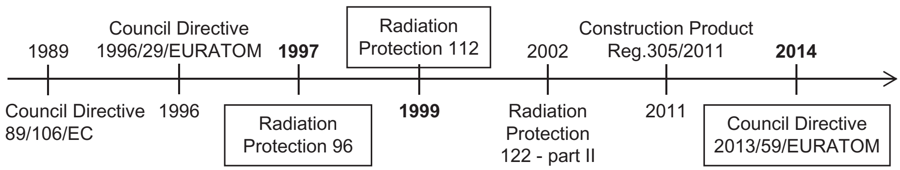


**Fig. 4.1** Timeline of EU guidance and regulations concerning natural radioactivity in building materials. *Boxes* evidence the most important steps.

recycling options for NORM residues, it is, however, vital to carefully consider current legislation and recommendations.

Council Directive 2013/59/Euratom, laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation (EU, 2014), considers the gamma exposure from building materials. Article 75 and Annex VIII of the Directive are devoted to this issue. This Directive shall be transposed into national legislations of Member States and in force before Feb. 2018.

Fig. 4.1 gives a timeline sketching the development of EU legislation on building materials. This starts with Council Directive 1996/29/Euratom which was the first legislation in which RP from natural sources of ionizing radiations was considered.

In Section 4.2, the different steps of this development are presented. In Section 4.3, current EU legislation on this topic is described.

Section 4.4 gives a short presentation of the drinking water Directive 2013/51/Euratom. This legislation needs to be allowed for in case of disposal of NORM residues, which may eventually apply to building rubble as well. Section 4.5 gives a synthetic overview of regulations already in force in EU Member States and in some other countries.

In Section 4.6, examples of current national legislations in some EU Member States are presented in detail and also the legislative approach for reuse of NORM in construction in Australia is described.

Finally, Section 4.7 offers a review of different tools elaborated in different EU and non-EU countries in order to characterize the radioactivity content of building materials and to evaluate their radiological impact.

## 4.2 Evolution of the EU legislative approach to natural radioactivity in building materials

In this section, a short review of guidelines and regulations issued by EU to deal with RP problems determined by natural radioactivity in building materials is presented.

### *4.2.1 Radiation protection 96*

In the 1990s the European Commission got interested in a possible common approach regarding exposure to enhanced natural radioactivity. Eventually, this resulted in a requirement in Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation (EU, 1996). The Directive merely required to identify work activities involving significantly increased levels of exposure for workers or members of the public to natural radiation sources which cannot be disregarded from a RP point of view. This requirement did, however, not consider explicitly natural radioactivity in building materials. Therefore, the European Commission contracted a study to the Finnish Radiation and Nuclear Safety Authority (STUK) with the aim "to provide the Commission with information about natural radioactivity in building materials and in industrial by-products used as raw materials for construction products and to enquire into existing relevant regulations in the Member States." The results of this study were published in 1997 as RP 96 (EC, 1997) and provided for the first time a document treating the natural radioactivity in building materials from a broad perspective.

Indeed, the document presented interesting results, in particular:

- a survey of radioactivity levels in normal or commonly used building materials in Europe
- the examination of materials with enhanced radioactivity used in building industry
- a discussion of the economic and ecological benefit of recycling industrial by-products and wastes
- a discussion about the RP basis applicable to this special question and the corresponding framework
- an assessment of radiation doses caused by radioactivity in building materials with a room model developed at STUK
- a survey of existing regulations on natural radiation and radioactivity of building materials

Building materials may also be of concern as a radon source, but RP 96 affirmed that "It is very unlikely that building materials with 'normal' radium concentrations could cause indoor radon concentrations exceeding 200 Bq $m^{-3}$, which is the upper value for new dwellings, recommended by the European Commission" [see European Commission Recommendation 90/143/Euratom on the protection of the public against indoor exposure to radon (EC, 1990)].

Finally, a proposal for a common European approach to the regulation of the radioactivity of building materials was presented. A reference level of 1 mSv per year was proposed for the annual dose contribution of gamma radiation from building materials "in addition to the individual dose received from background gamma radiation from the undisturbed earth's crust" (RP 96). The selected reference level, 1 mSv per year, is the same as the dose limit for public exposures to practices, including industrial sectors involving naturally occurring radioactive material. The "STUK model" (Markkanen, 1995) was introduced as a precautionary evaluation tool of the radiological impact of building materials according to their use (bulk or minor/superficial use).

### 4.2.2 Radiation protection 112

The information collected in the RP 96 publication was used as a basis for the elaboration of Community guidance in RP 112—"Radiological protection principles concerning the natural radioactivity of building materials" (RP 112), published in 1999 (EC, 1999). This guidance was adopted by the Article 31 Group of Experts and published by the European Commission to "be a useful reference document for the European Commission when considering possible regulatory initiatives at Community level" (EC, 1999).

In RP 112 the index $I$, already used in RP 96 to evaluate annual doses from building materials, was introduced as a conservative screening tool to identify materials that need supplementary investigations, starting from the basic assumption that "All building materials contain some natural radioactivity." RP 112 noted that "small, unavoidable exposures need to be exempted from all possible controls" and considered that "a uniform exemption level within the European Union would allow free movement of most building materials within the EU" (EC, 1999).

The guidance RP 112 suggests basing the radioactivity control of building materials on a dose criterion and an exemption level. Therefore, "threshold" values for index $I$ are calculated based on two dose criteria (0.3 and 1 mSv per year) and two categories to account for ways and amounts in which the material is used in a building (bulk or superficial). In this approach, the dose criterion is defined as the dose exceeding the mean environmental outdoor background in Europe of $50\,\mathrm{nGy\,h^{-1}}$ ($\sim$0.25 mSv per year with an indoor occupancy factor of 0.8) in 1999, as probably taken from the UNSCEAR 1993 Report (UNSCEAR, 1993).

RP 112 defines an index $I$ in the following equation:

$$I = \frac{C_{\mathrm{Ra-226}}}{A_{\mathrm{Ra-226}}} + \frac{C_{\mathrm{Th-232}}}{A_{\mathrm{Th-232}}} + \frac{C_{\mathrm{K-40}}}{A_{\mathrm{K-40}}} \tag{4.1}$$

In RP 112 Eq. (4.1) $A_{\mathrm{Ra\text{-}226}}$, $A_{\mathrm{Th\text{-}232}}$, and $A_{\mathrm{K\text{-}40}}$ are 300, 200, and 3000 $\mathrm{Bq\,kg^{-1}}$, respectively. $A_{\mathrm{Ra\text{-}226}}$, $A_{\mathrm{Th\text{-}232}}$, and $A_{\mathrm{K\text{-}40}}$ are calculated for a "standard room" with the following characteristics: size $4\ \mathrm{m} \times 5\ \mathrm{m} \times 2.8\ \mathrm{m}$; walls, ceiling, and floor are made of concrete with density $= 2300\ \mathrm{kg\,m^{-3}}$ and thickness $= 0.2$ m.

In particular, when materials are used in bulk amounts, indoor annual doses of 0.3 and 1 mSv correspond to an index $I$ of 0.5 and 1, respectively. When materials are superficial or with restricted use (tiles, boards, etc.) the values of index $I$ corresponding to the annual values of 0.3 and 1 mSv are 2 and 6, respectively. In Table 4.1 values of the index $I$ corresponding to the dose criteria are summarized.

It is worth mentioning that the RP 112 (EC, 1999) addressed the "Rn issue" by stating that: "When gamma doses are limited to levels below 1 mSv per year, the $^{226}$Ra concentrations in the materials are limited, in practice, to levels which are unlikely to cause indoor radon concentrations exceeding the design level of the Commission Recommendation (*in that time 200 Bq m*$^{-3}$) (EC, 1990)."

**Table 4.1 Values of index *I* for different dose criteria and uses**

| Annual dose criterion | 0.3 mSv | 1 mSv |
|---|---|---|
| Materials used in bulk amounts, e.g., concrete | $I \leq 0.5$ | $I \leq 1$ |
| Superficial and other materials with restricted use: tiles, boards, etc. | $I \leq 2$ | $I \leq 6$ |

### 4.2.3 Radiation protection 122 part II

The concepts of exemption of practices and clearance of materials containing artificial radioactivity were introduced in Council Directive 96/29/Euratom (EU, 1996). The general exemption and clearance criteria state that (1) the radiological risk to individuals is sufficiently low, (2) the practice is justified, and (3) the practice is inherently safe (EU, 1996, 2013). While for artificial radionuclides this general framework was translated into a dose criterion and into calculated exemption values, this was not the case for natural radioactive materials. The application of the framework to natural radioactive materials was addressed in later guidance—RP 122—part II (EC, 2002). RP 122 II deals with the handling, processing, use, and disposal of NORM residues and the relevant radiological consequences. The document considers ten exposure scenarios for workers and another three for the population, including dwellings built with NORM-containing building materials, in order to determine the activity concentrations to be used as general exemption or clearance levels (GCL) for NORM. The model applied in the "dwelling exposure scenario" uses parameters that differ from those of the RP 112 scenario (see Section 4.2.2). In this model, the room size is 3 m × 4 m × 2.5 m, the number of walls made of building material (concrete) containing NORM is 2, to consider the presence of doors and windows. The annual dose criterion applied is 300 μSv. Additionally, the dilution factor of NORM used as concrete component is taken normally as 30%, except for 10% for fly ash.

If the content of naturally occurring radionuclides is above the clearance level shown in Table 4.2 then a radiological impact assessment must be made to demonstrate that the dose increment for the members of the public, in addition to the prevailing background radiation, is not more than 300 μSv per year (EC, 2002).

**Table 4.2 Rounded general clearance levels for naturally occurring radionuclides in all types of solid materials as proposed by radiation protection 122 II**

| Radionuclide | Activity concentration (kBq $kg^{-1}$) |
|---|---|
| $^{238}$U*sec* incl. $^{235}$U*sec*[a] | 0.5 |
| Natural U | 5 |
| $^{230}$Th | 10 |
| $^{226}$Ra+ | 0.5 |
| $^{210}$Pb+ | 5 |
| $^{210}$Po | 5 |
| $^{232}$Th*sec* | 0.5 |
| $^{232}$Th | 5 |
| $^{228}$Ra+ | 1 |
| $^{228}$Th+ | 0.5 |
| $^{40}$K | 5 |

[a] $^{238}$U*sec* and $^{235}$U*sec* are in their fixed natural ratio (99.275% and 0.72% atomic fraction).
(From RP 122 II)

The General Clearance and Exemption levels as elaborated in RP 122 II were aimed to provide for clearance of NORM residues and for exemption of NORM activities. Hence the use of NORM residues as a component of building materials was considered but the specific radiological concern about building materials as a radiation source was not within the scope of RP 122 II.

## 4.3 Council Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation

Different types of building materials are considered in Council Directive 2013/59/Euratom (EU, 2014) and in particular in article 75 of this Directive. Annex XIII provides an indicative list of building materials of concern—divided into natural materials and materials incorporating residues from NORM processing industries. In article 75 it is also stated that the reference level for the indoor external exposure to gamma radiation from building materials is 1 mSv per year, in addition to the outdoor external exposure. So, the Council Directive uses 1 mSv per year as a reference level instead of 300 μSv proposed in RP 122 II (EU, 2014; EC, 2002). Member States can make their legislation more stringent, however, as explicitly stated in the Directive.

Building materials as a radon source are dealt with in the Annex XVIII of this Directive, listing items to be considered in preparing the national action plan to address long-term risks from radon exposure.

Annex VIII is focused on the use of the activity concentration index *I*. The index is taken in the form as defined in the RP112 (EC, 1999), but only for bulk use, and introduced as a tool to identify materials that need supplementary investigations. Indeed, building materials are considered to be of concern from a RP point of view when the value of index *I* exceeds 1 (corresponding to a reference level of 1 mSv per year from calculations in RP 112 (EC, 1999)). Annex VIII states that the index *I* is a conservative screening tool, and for building materials of concern "the calculation of dose needs to take into account other factors such as density, thickness of the material as well as factors relating to the type of building and the intended use of the material (bulk or

**Table 4.3 Activity concentrations for exemption or clearance of naturally occurring radionuclides in solid materials in secular equilibrium with their progeny**

| Radionuclide | Activity concentration (kBq $kg^{-1}$) |
|---|---|
| Natural radionuclides from the $^{238}U$ series | 1 |
| Natural radionuclides from the $^{232}Th$ series | 1 |
| $^{40}K$ | 10 |

From Table A Part 2 of Annex VII of the Council Directive 2013/59/Euratom (EU, 2014).

superficial)." A detailed description of the index *I* and other tools to assess the gamma dose rate from building materials is reported in Section 4.7.

When recycling NORM residues in building materials is not a feasible option, the Annex VII of the Council Directive 2013/59/Euratom provides the exemption and clearance levels in terms of activity concentrations for naturally occurring radionuclides in solid materials (see Table 4.3) (EU, 2014). These values can be applied by default to any amount and any type of solid material to be cleared for reuse, recycling, conventional disposal, or incineration (EU, 2014). As the destination of the material is often not known in advance, these general clearance and exemption levels are defined as default minimum values. Member States may specify dose criteria (smaller than 1 mSv per year) for specific types of practices or specific pathways of exposure involving natural occurring radionuclide.

The activity concentrations listed in Table 4.3 apply to all radionuclides of the decay chain of $^{238}U$ or $^{232}Th$ in solid materials in secular equilibrium with their progeny. The EU-BSS does not exclude that for segments of the decay chain, which are not in equilibrium with the parent radionuclide, higher values may be applied, e.g., for $^{210}Po$ and $^{210}Pb$.

### 4.3.1 Council Directive 2013/59/Euratom and CPR 305/2011

In Jul. 2013, the Construction Products Directive 89/106/EEC was replaced by a directly applicable CPR (305/2011/EU) laying down requirements for the marketing of construction products. Directive 89/106/EEC had put the "emission of dangerous radiation" in the list of the "essential requirements"—concerning hygiene, health, and the environment—to be satisfied by construction works. However, this generic statement was, so far, not translated in standards for the RP of workers of the public linked to general construction works. So, only Council Directive 2013/59/Euratom deals specifically with radioactivity in building materials

In the CPR, "dangerous radiation" is again mentioned in the "ANNEX I—Basic requirements for construction works," hence giving the radiological characteristics of construction materials stronger emphasis. In fact, "dangerous radiation" together with other toxic and dangerous agents may not to become a "threat to the hygiene or health and safety of workers, occupants or neighbors, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition, etc."

The intention of the CPR is

**i.** to provide for a system of harmonized technical specifications for construction products
**ii.** to establish harmonized rules on how to detail the performance of construction products in relation to certain essential characteristics
**iii.** to provide for the CE marking of products

As far as radiation is concerned, the construction works must be designed and built in such a way that the emission of dangerous radiation will not be a threat to the health of the occupant or neighbors.

It is important to emphasize that the CPR does not harmonize regulations and requirements concerning the actual construction product. It only harmonizes which product characteristics are relevant for consideration and it harmonizes the technical means of determining the product's performance in relation to these essential characteristics. Member States and public and private sector procurers are free to set their own requirements for the performance of the products and therefore on the performance level. The performance level of 1 mSv per year for building materials is laid down in the Council Directive 2013/59/Euratom.

The 2013/59 Euratom Directive refers to the CPR regulation (which was published three years earlier), stating (in the "preamble") that

> ***(19)*** *Building materials emitting gamma radiation should be within the scope of this Directive but should also be regarded as construction products as defined in Regulation (EU) No 305/2011, in the sense that Regulation applies to construction works emitting dangerous substances or dangerous radiation.*
>
> ***(20)*** *This Directive should be without prejudice to the provisions of Regulation (EU) No 305/2011 on the declaration of performance, the establishment of harmonized standards or the means and conditions for making available the declaration of performance or with regard to CE marking.*
>
> ***(21)*** *Regulation (EU) No 305/2011 requires information to be made available when products are placed on the market. This does not affect the right of Member States to specify in national legislation requirements for additional information they deem necessary to ensure radiation protection.*

Under the general rules of the Euratom Treaty, Members States are obliged to transform requirements of the Directive into national system of regulation by 6th of February 2018. To facilitate good implementation of the CPR, harmonized procedures for determining the radiological characteristics in construction products are required. The product information obtained through these procedures will be used in the declaration of performance or with regard to CE marking of building materials. For this purpose, the European Committee for Standardization (CEN)—mandated by the European Commission—has established the Technical Committee (TC351) in Nov. 2005 to develop horizontal standardized assessment methods for harmonized approaches relating to the release of dangerous substances under the CPR.

The development of harmonized methods in relation to radiation is carried out under Working Group 3 (WG3). The WG3 has drafted a Technical Specification (TS) for the determination of the activity concentrations from radium-226, thorium-232, and potassium-40 in construction products using gamma-ray spectrometry. The TS describes the sample preparation and the sample measurement and includes procedures for energy and efficiency calibration and analysis of the spectrum. The specification is based on the Dutch NEN 5697 (NEN, 2001). After completion of the TS the specification will be proposed for a European norm (EN). The WG3 has also drafted a technical report on the dose assessment of emitted gamma radiation from construction products. The report is intended to provide a harmonized dose assessment approach that accounts for factors such as density or thickness of the material as well as factors relating to the type of construction and the intended use of the material (bulk or superficial) (Hoffmann, 2014). This approach is especially needed for building materials with an index exceeding 1 but that nonetheless may still comply with the 1 mSv per year reference level.

## 4.4 Drinking water Directive

At first glance, there is no direct link between drinking water and building materials, but when their entire life cycle is considered, the possibility that they and/or their rubble can contaminate water by environmental pathways must be considered. This was intended to apply to NORM processing industries rather than construction works, as is pointed out in the article 25(3) of the Council Directive 2013/59/Euratom that states:

> *3. Notwithstanding the exemption criteria laid down in Article 26 (i.e. clearance levels, see tab 3), in situations identified by Member States where there is concern that a practice identified in accordance with Article 23 may lead to the presence of naturally-occurring radionuclides in water liable to affect the quality of drinking water supplies or affect any other exposure pathways, so as to be of concern from a radiation protection point of view, the competent authority may require that the practice be subject to notification.*

For the specific scenario in which one of the exposure pathways to natural or artificial radioactivity is through drinking water ingestion, dose to population is regulated by the Council Directive 2013/51/Euratom which lays down the requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption (EU, 2013). This Directive supersedes Directive 98/83/EC on the quality of water intended for human consumption "…as regards the requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption." Indeed, the Directive 98/83/EC dealt with all the pollutants in drinking water. Due to the Euratom Treaty competence in any situation of radiological exposure, Council Directive 2013/51/Euratom was issued specifically for radioactivity in drinking water.

Besides radon and tritium, considered separately, a special term was coined, indicative dose (ID). The indicative dose is defined as the effective committed dose obtained from all the radionuclides (natural and artificial) present/detected in drinking water but excluding tritium, radon, short-lived radon decay products, and $^{40}K$. The parametric value for ID was set at 0.1 mSv per year. Based on this value, specific annual intake values, and dose per unit intake, a list of derived concentration values is provided for the most common natural (Table 4.4) and artificial radionuclides (but can also be calculated for other radionuclides that are not in the list). If a screening is performed for certain radionuclides and the activity concentration exceeds 20% of the corresponding derived value an analysis of additional radionuclides is required. When

**Table 4.4 Derived concentrations for naturally occurring radionuclides in drinking water**

| Radionuclide | Derived concentration (Bq $L^{-1}$) |
|---|---|
| $^{238}U$ | 3.0 |
| $^{234}U$ | 2.8 |
| $^{226}Ra$ | 0.5 |
| $^{228}Ra$ | 0.2 |
| $^{210}Pb$ | 0.2 |
| $^{210}Po$ | 0.1 |

From Annex III of the Council Directive 2013/51/Euratom.

multiple radionuclides are present, the weighted sum of the concentrations of the individual radionuclides needs to be smaller or equal to 1 in order to be below the indicative dose of 0.1 mSv per year.

Instead of screening for individual radionuclides, it is also possible to measure gross alpha and beta activity with their corresponding screening levels of 0.1 Bq $L^{-1}$ for gross alpha activity and 1.0 Bq $L^{-1}$ for gross beta activity. If the measured activities are below their screening levels, it can be assumed that the indicative dose is less than 0.1 mSv per year; otherwise, a screening for specific radionuclides is required. The clearance levels set for NORM in solid materials and calculated according to RP 122 II (Table 4.2) are around three orders of magnitude higher than the derived concentration values in water (Table 4.4). This is why it is prudent to take into account the possibility of water contamination in case of long-term direct contact with rubble.

## 4.5 Analysis of national legislations

In Table 4.5 the legislation and recommendations currently (end of 2016) in use in EU and non-EU countries are summarized. These regulations have socio-economic consequences because they are used for banning the use and trade of materials exceeding the defined dose criteria. For screening and evaluation of construction materials several screening tools are in use that are summarized in Table 4.5 with the adopted screening tool reference values (decision values for a given index)[1] The activity concentration index approach is widely used in different national legislations and recommendations. However, values of parameters and formula of indexes may significantly vary between countries. Other differences may arise due to considerations on activity concentration in typical building materials in each country and their final utilization,

[1] The $Ra_{eq}$ method, introduced by Beretka and Mathew (1985), is based on the definition of radium equivalent activity:

$$Ra_{eq} = C_{Ra-226} + 1.43C_{Th-232} + 0.077C_{K-40} \leq 370$$

$Ra_{eq}$ uses dose criteria of 1.5 mGy per year, which corresponds to approximately 1 mSv per year and, approximately, to 370 Bq $kg^{-1}$ of $^{226}Ra$, 260 Bq $kg^{-1}$ of $^{232}Th$, and 4800 Bq $kg^{-1}$ $^{40}K$. In the $Ra_{eq}$ equation, exposure to gamma radiation is controlled by limiting $Ra_{eq} \leq 370$ Bq $kg^{-1}$.

**Table 4.5** **Summary of the legislation and recommendations still in use in EU and non-EU countries**

| Country | Index | Decision values | End-use of building materials | Dose criterion (mSv per year) |
|---|---|---|---|---|
| *EU countries* | | | | |
| Council Directive 2013/59/ Euratom (EU, 2014) | $I_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$ | $I \le 1$ | | 1 |
| Austria[a] (Austrian Standard Institute, 2009) ÖNORM S 5200: 2009 | $I = \frac{C_{Ra-226}}{880}(1 + 0.07\varepsilon pd) + \frac{C_{Th-232}}{530} + \frac{C_{K-40}}{8800}$ | $I \le 1$ | | 1 |
| Czech Republic (Hulka et al., 2008) | $I_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$; $C_{Ra}\,\mathrm{Bq\ kg^{-1}}$ | $I \le 0.5$<br>$C_{Ra} \le 150$<br>$I \le 1$<br>$C_{Ra} \le 300$<br>$I \le 2$<br>$C_{Ra} \le 300$ | Bulk material (e.g., brick, concrete, gypsum)<br>Raw material (e.g., sand)<br><br>Superficial material (e.g., tiles) | 0.3 |
| Finland (STUK, 2010) | $I_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$<br>$I_2 = \frac{C_{Ra}}{700} + \frac{C_{Th}}{500} + \frac{C_K}{8000} + \frac{C_{Cs}}{2000}$ | $I_1 \le 1$<br>$I_1 \le 6$<br>$I_2 \le 1$<br><br>$I_2 \le 1.5$ | Bulk material<br>Superficial material<br>Bulk material for road constructions<br>Superficial material for road constructions | 1<br><br>0.1 |

*Continued*

**Table 4.5 Continued**

| Country | Index | Decision values | End-use of building materials | Dose criterion (mSv per year) |
|---|---|---|---|---|
| Poland (Poland Government, 2007) | $f_1 = \frac{S_{\mathrm{Ra}}}{300} + \frac{S_{\mathrm{Th}}}{200} + \frac{S_{\mathrm{K}}}{3000}$; <br> $f_2 = S_{\mathrm{Ra}}\,\mathrm{Bq\,kg}^{-1}$ | $f_1 + \Delta f_1 \leq 1.2$ <br> $f_2 + \Delta f_2 \leq 220$ | Dwelling: for civil engineering construction indexes can be multiplied up to four times | 1 |
| *Non-EU countries* | | | | |
| Albania (Albania Government, 2011) | $I_1 = \frac{C_{\mathrm{Ra}}}{300} + \frac{C_{\mathrm{Th}}}{200} + \frac{C_{\mathrm{K}}}{3000}$ | $I_1 \leq 1$ | Bulk material | 1 |
| | $I_2 = \frac{C_{\mathrm{Ra}}}{700} + \frac{C_{\mathrm{Th}}}{500} + \frac{C_{\mathrm{K}}}{8000} + \frac{C_{\mathrm{Cs}}}{2000}$ | $I_2 \leq 1$ | Bulk material for road constructions | |
| China (Standardization Administration of the People's Republic of China, 2010) GB 6566-2010 | $I_{\mathrm{r}} = \frac{C_{\mathrm{Ra}}}{370} + \frac{C_{\mathrm{Th}}}{260} + \frac{C_{\mathrm{K}}}{4200}$; $I_{\mathrm{Ra}} = \frac{C_{\mathrm{Ra}}}{200}$ | $I_{\mathrm{Ra}} \leq 1.0$ <br> $I_{\mathrm{r}} \leq 1.0$ | Bulk material | 1 |
| | | $I_{\mathrm{Ra}} \leq 1.0$ <br> $I_{\mathrm{r}} \leq 1.3$ | Superficial and 25% hollow bulk material for dwelling constructions | |
| | | $I_{\mathrm{Ra}} \leq 1.3$ <br> $I_{\mathrm{r}} \leq 1.9$ | Superficial material for industrial constructions | |
| | | $I_{\mathrm{r}} \leq 2.8$ | Superficial material for outside use | |

| | | | | |
|---|---|---|---|---|
| Israel[a,b] (Kovler, 2011)—SI_5098: 2009 | $I=\frac{A_{Ra}}{A_1}(1-\epsilon)+\frac{A_{Ra}}{A_2}\epsilon+\frac{A_{Th}}{A_3}+\frac{A_K}{A_4}$<br>$I_\gamma=\frac{A_{Ra}}{A_1}+\frac{A_{Th}}{A_3}+\frac{A_K}{A_4}$ | $I\leq 1$<br>$I\leq 0.8$<br>$I\leq 0.4$<br>$I\leq 0.32$ | Bulk material<br>Superficial material<br>Bulk material<br>Superficial material | 0.3 |
| Russia (State Committee for the Russian Federation for Standardization and Metrology, 1994) GOST 30,108-94 | $A_{eff}\,\mathrm{Bq\,kg^{-1}}=A_{Ra}+1.3A_{Th}+0.09A_K$ | $A_{eff}+\Delta A_{eff}$<br>$\leq 370$<br>$\leq 740$<br>$\leq 1500$ | Dwelling/public constructions<br>Industrial construction<br>Road constructions | 1 |
| Serbia Official Gazette of Serbia 86/2011[b] | $I_1=\frac{C_{Ra}}{300}+\frac{C_{Th}}{200}+\frac{C_K}{3000}$<br>$I_1=\frac{C_{Ra}}{400}+\frac{C_{Th}}{300}+\frac{C_K}{5000}$<br>$I_1=\frac{C_{Ra}}{700}+\frac{C_{Th}}{500}+\frac{C_K}{8000}$ | $I_1\leq 1$<br>$I_1\leq 1$<br>$I_1\leq 1$ | Bulk material<br>Bulk material for outside use<br>Bulk material for road constructions | 1 |

[a] If emanation coefficient it is not known: in Austria $\varepsilon=10\%$ can be used; in Israel $\varepsilon=6\%–7\%$ for masonry block; and $\varepsilon=12\%$ for other building materials including concrete.
[b] The $A_{K\text{-}40}$, $A_{Ra\text{-}226}$, $A_{Th\text{-}232}$ values depend on the density and thickness of the building product.

different environmental background, and not the least the standard room model applied. The main differences are listed as follows.

- Many countries, e.g., Russia, use the radium equivalent activity concentration $Ra_{eq}$ (see note[1]).
- In general, both EU and non-EU countries use 1 mSv per year as dose criteria. This annual dose is meant in excess to the average outdoor background which in the EU is 50 nGy $h^{-1}$. The Austrian legislation uses an average dose rate of approximately 240 nGy $h^{-1}$ (Austrian Standard Institute, 2009). Israel uses a dose criterion of 0.3 mSv per year exceeding background which is "*the average dose which would be received in a house built from materials with 'typical' activities*" (Markkanen, 2001). For the Finish legislation, an activity concentration index for "streets and playgrounds" (bulk material for road construction) larger than 1 indicates an effective gamma dose larger than 0.1 mSv per year while for the evaluation of building materials the dose criterion 1 mSv per year is used but both calculations are based on very different dose models (Markkanen, 1995).
- Regarding the activity concentration in building material it is worth highlighting that Nordic countries (like Finland) include also the presence of $^{137}Cs$ due to the Chernobyl accident.
- The screening indexes do not generally take radon emanation into account with the exception of Austria and Israel. On the other hand, many countries tried to account for radon exhalation by limiting the $^{226}Ra$ activity concentration, e.g., China, Czech Republic, and Poland.
- The determination of activity concentration is essential for accurately determining the activity concentration index; however, only the Russian and Polish legislations include the uncertainty in the determination of the index as: $A_{eff} + \Delta A_{eff} \leq 370 \mathrm{Bq/kg}$ and index $I + \Delta$index $I \leq 1.2$, respectively. In general, in different countries, it is only recommended that the relative uncertainty on the measurement should not be higher than 20%. As $^{232}Th$ does not contribute directly to gamma radiation, this is not the most relevant radionuclide to be considered in a screening index that is evaluating the gamma dose. The use of $^{232}Th$ in an index is only relevant in case of secular equilibrium in the whole thorium decay series. Moreover, $^{232}Th$ being an alpha emitter in not easily measurable and in practice, its decay products $^{228}Ra$ (by $^{228}Ac$) and/or $^{228}Th$ (by $^{208}Tl$) are measured by gamma spectrometry. As the equilibrium state is often disturbed in NORM and NORM-containing building materials the use of the considered decay products, instead of $^{232}Th$, in relevant formulas is more appropriate. This aspect was accounted for in the Polish and Austrian regulations.

## 4.6 Examples of national legislations

In the next sections several examples of EU legislations and one example of a non-EU national legislation are discussed more in depth. For most EU Member States, as a result of the transposition of Council Directive 2013/59/Euratom, it is the first time that they are preparing national regulations dealing with the radioactivity in building materials.

### 4.6.1 Austria

In 1995, an index *I* that accounts for exposure from both gamma radiation and radon exhalation from building materials was established in the Austrian legislation (Austrian Standard Institute, 1995).

$$I = (1 + 0.15k)C_{\text{Ra}-226}/1000\,\text{Bq}\,\text{kg}^{-1} + C_{\text{Th}-232}/600\,\text{Bq}\,\text{kg}^{-1} + C_{\text{K}-40}/10{,}000\,\text{Bq}\,\text{kg}^{-1} \leq 1 \tag{4.2}$$

where $k$ is a constant which depends on some characteristics of the materials, i.e., density, thickness, and radon emanation power. The dose criterion used to calculate the $A_x$ values for $^{226}$Ra, $^{232}$Th, and $^{40}$K is 2.5 mSv per year.

In 2009 a new regulation was issued, which improved the radon contribution estimate to the excess indoor effective dose (Austrian Standard Institute, 2009) changing the index definition in this way:

$$I = (1 + 0.07\varepsilon\rho\delta)C_{\text{Ra}-226}/880\,\text{Bq}\,\text{kg}^{-1} + C_{\text{Th}-232}/530\,\text{Bq}\,\text{kg}^{-1} + C_{\text{K}-40}/8800\,\text{Bq}\,\text{kg}^{-1} \leq 1 \tag{4.3}$$

where $\varepsilon$ is the radon emanation power, $\rho$ the wall density, $d$ the wall thickness, and 0.07 is a constant, expressed in (m$^2$ kg$^{-1}$). When disequilibrium in thorium decay series is noticed then the $^{232}$Th activity concentration is calculated as:

$$C_{\text{Th}-232} = 0.5(C_{\text{Ra}-228} + C_{\text{Th}-228})$$

The dose criterion used to calculate the $A_x$ values for $^{226}$Ra, $^{232}$Th, and $^{40}$K is 1 mSv per year exceeding the assumed outdoor background dose of 1.2 mSv per year. More details on this Austrian index are reported in Section 4.7.5.

### 4.6.2 Belgium

For recycling NORM residues into building material, the activity concentration of a single batch of NORM residues should typically not exceed 10 kBq kg$^{-1}$ and a control on the resulting activity concentration in the produced building material must be made by the operator. For building materials used in habitation, the activity index $I = 1$ is used as a reference level. The clearance levels of Table 4.2 are used for other building materials, like materials used in road construction.

### 4.6.3 Czech Republic

Starting from 1970, the Czech Republic had to face a serious situation with several thousand houses built with material rich in radium or contaminated with residues from uranium paint and radium factories (with $^{226}$Ra activity concentration up 1 MBq kg$^{-1}$). The Czech Republic is also one of the countries with the highest indoor radon concentration in the world (mean radon concentration = 140 Bq m$^{-3}$) (Hulka et al., 2008).

For the above reasons, in 1987 the Czech Republic had to introduce an ad hoc legislation stating interventional levels for already existing houses, which is the only example found in literature of the use of an index to identify existing dwellings of concern. For this purpose, the following index $S$ was introduced, in order to limit both gamma and indoor radon exposures in dwellings:

**Table 4.6 Limit values for $^{226}$Ra in the Czech Republic legislation**

| Type of building material | $^{226}$Ra limit value (Bq kg$^{-1}$) | |
|---|---|---|
| | **Buildings where people live or stay** | **Other constructions where people do not live or stay** |
| Material used in bulk amount (e.g., brick, concrete, gypsum) | 150 | 500 |
| Other material used in small amounts (e.g., tile, etc.) and raw material (sand, building stone, gravel aggregate, bottom ash, etc.) | 300 | 1000 |

$$S = D/2\,\mu\text{G}\gamma\,\text{h}^{-1} + C_{\text{Rn}}/400\,\text{Bq}\,\text{m}^{-3} \tag{4.4}$$

where $D$ is the gamma dose rate (μGy h$^{-1}$) and $C_{\text{Rn}}$ the annual average radon concentration (Bq m$^{-3}$). This index results from the choice of a recommended value of 400 Bq m$^{-3}$ for radon activity concentration, and 2 μGy h$^{-1}$ for indoor gamma dose rate, to remediate existing buildings. "This sum rule (used only if $D > 2$ μGy h$^{-1}$) and value $S = 1$ were used for decision making on remedial measures with governmental support" (Hulka et al., 2008). For new houses, the limit value for $^{226}$Ra was calculated in order to keep ≤ 30% the building material contribution to the indoor radon limit value (200 Bq m$^{-3}$). With a room model under conservative conditions, the resulting limit value for $^{226}$Ra was 120 Bq kg$^{-1}$. As reported by Hulka et al. (2008), "The other systems of regulation based on limitations for radon exhalation rate or emanation coefficient were discussed but rejected at the end because of sophisticated measurements of exhalation, long-term changes, and the complicated system of limitation proposed."

The present Czech legislation concerning radioactivity in building materials is based on a two-step procedure to account for both gamma and radon exposure (Hulka et al., 2008): firstly, the index $I$, as defined by the RP 112 document (EC, 1999), is used as a screening tool. Producers and importers should ensure systematic measurements of natural radionuclides in building materials and submit the results to the State Office for Nuclear Safety. If the index $I$ is higher than 0.5—a value corresponding to the exemption level of 0.3 mSv per year—a cost-benefit analysis should be done by the producer with a criterion aimed at reducing the public doses to a level as low as reasonably achievable (see details in Hulka et al., 2008). In the second step, in order to control radon exhalation from building materials, the producer must also apply the limit levels for $^{226}$Ra activity concentrations of Table 4.6.

### 4.6.4 Example of a non-European approach: Australia

In Australia, materials containing natural radioactivity are generally subject to regulatory consideration dependent upon the radionuclide concentration and the radionuclide quantity. This is also the case for by-products or wastes from existing processes that may be used in construction materials.

The largest volumes of material that may be useful in construction are generated from mining and processing operations within Australia. While most of the material is disposed under appropriate mining regulation; in some case, the material may be used in activities such as road construction or as part of building materials. In these cases, it may only be used after approval from the appropriate authority.

Australia is a federation of states and territories and this has resulted in the development of different laws and regulations at a national level and also at individual State and territory level. Generally, the overall regulatory approach to NORM in Australia is guided by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and the guidance is based on the International Atomic Energy Agency (IAEA) framework. State and territories then tend to adopt the guidance into regulation.

ARPANSA publishes a series of NORM-related documents as part of its Radiation Protection Series (http://www.arpansa.gov.au/) and these include

- Radiation Fundamentals: Fundamentals for Protection Against Ionizing Radiation (2014).
- Codes of Practice and Standards: These are detailed documents which are usually adopted in state-based regulation.
- Guides and Recommendations: General documents which provide practical advice and assistance for regulators or operators.

The primary ARPANSA NORM-related document is *Safety Guide for the Management of Naturally Occurring Radioactive Material* (*NORM*), published in 2008. The document essentially follows the guidance provided by the IAEA about the application of the concepts of exclusion, exemption, and clearance (IAEA, 2004a) and the IAEA Safety Guide about occupational RP in the mining and processing of raw materials (IAEA, 2004b).

## 4.7 Screening tools

### 4.7.1 Different approaches to modeling

In general, an index is used to estimate the gamma dose rate from the activity concentration in building material (EC, 1997). The index is the sum of the ratios of specific activities of various nuclides relative to reference values. In order that the material complies with the screening criterion, the index should not typically exceed the value of *1*:

$$I = \frac{C_{\mathrm{Ra-226}}}{A_{\mathrm{Ra-226}}} + \frac{C_{\mathrm{Th-232}}}{A_{\mathrm{Th-232}}} + \frac{C_{\mathrm{K-40}}}{A_{\mathrm{K-40}}} \leq 1 \qquad (4.5)$$

where $C_x$ (Bq kg$^{-1}$) is the measured activity concentration and $A_x$ (Bq kg$^{-1}$) is the fixed reference value. The $A_x$ values are calculated after assuming a dose criterion to be complied with and a background to be subtracted. These values also depend on the geometrical and structural characteristics of the indoor environment (room size, density, thickness of materials, etc.) and the dose rate coefficients per unit activity concentration (i.e., the room model) used. Finally, the outdoor background subtracted from the indoor dose rate might play a significant role. For this reason, $A_x$ values might significantly vary among EU countries if the country-specific outdoor background were accounted to calculate $A_x$. These indexes are generally conservative tools, elaborated for screening purpose.

### 4.7.2 The EU BSS index

As mentioned already in Section 4.3, the EU BSS (Article 75, Annex XIII) (EU, 2014) introduces a screening index $I_{\text{BSS}}$ in order to identify building materials that might be of concern from the RP point of view, "taking into account the indicative list of building materials set out in Annex XIII" of the EU BSS. This index, the first time proposed in RP 112 (EC, 1999), is the application of the "general index," shown in the previous paragraph, calculated in a specific case that will be described.

In the $I_{\text{BSS}}$ formula

$$I_{\text{BSS}} = \frac{C_{\text{Ra}-226}}{300} + \frac{C_{\text{Th}-232}}{200} + \frac{C_{\text{K}-40}}{3000} \leq 1 \tag{4.6}$$

the $A_x$ parametric values in generic index expression (1) calculated for Ra-226, Th-232, and K-40 are 300, 200, and 3000, respectively. These $A_x$ values were obtained assuming: (i) a dose criterion of 1 mSv per year—as the excess to the average background originating from the Earth's crust, (ii) an annual occupancy factor of 7000 h, and (iii) a conversion coefficient 0.7 Sv $\text{Gy}^{-1}$. The background dose rate, corresponding to an average value outdoors in Europe, was assumed to be 50 nGy $\text{h}^{-1}$. With the cited hypotheses, 50 nGy $\text{h}^{-1}$ correspond to about 0.25 mSv per year. Elaboration of $A_x$ in $I_{\text{BSS}}$ is based on specific prerequisites that do not always represent a given situation that is being evaluated. The following assumptions are linked to the $I_{\text{BSS}}$: (1) the room dimensions are 4 m × 5 m × 2.8 m, (2) all surfaces (walls, floor, and ceiling) are assumed to be made from the same material (concrete of density = 2350 kg $\text{m}^{-3}$ and thickness of 0.2 m), (3) no presence of windows or doors, etc., is assumed. The room size is not a critical parameter, as demonstrated by Risica et al (2001)]. The assumption regarding the absence of windows and doors does not strongly influence the indoor gamma dose rate particularly considering its screening aim. On the contrary, thickness and density are the key characteristics of building materials that mostly affect the gamma irradiation indoors. A higher density and/or thickness results in a higher gamma irradiation. This aspect of $\text{I}_{\text{BSS}}$ is also considered in the EU BSS. Indeed, Annex VIII states that when $I_{\text{BSS}}$ of the considered building material exceeds 1 (corresponding to a reference level of 1 mSv per year), that "the calculation of dose needs to take into account other factors such as density, thickness of the material as well as factors relating to the type of building and the intended use of the material (bulk or superficial)." Considering that $I_{\text{BSS}}$ parameters are calculated for a dense and thick building material, i.e., concrete of density = 2350 kg m$^{-3}$ and thickness of 0.2 m, any other material of lower density and/or lower thickness is screened with a tool that is too conservative.

### 4.7.3 A new family of screening tools

In order to obtain a more realistic screening tool which better represents the gamma radiation properties of building materials, i.e., one that will allow for a conservative but realistic discrimination of building materials, in the last decade other tools accounting for density and thickness were developed. Confirming the need for this kind of tools, in the framework of the EU CPR No. 305/2011 (EU, 2011), the working group WG3 "Radiation from construction products" of the CEN/TC351 "Construction products: assessment of release of dangerous substances" received the mandate to screen possible ways for calculating the dose determined by gamma rays from building products with known concentrations of natural radionuclides (Hoffmann, 2014).

### 4.7.4 Israeli index

In 2009, Israel issued the standard SI 5098 for building materials radioactivity (Standards Institution of Israel, 2009). It should be pointed out, however, that this is not a screening tool, but a *standard*. This standard accounts for both gamma radiation and radon exhalation from building material, and introduces a total activity concentration index $I$:

$$I = \frac{C_{\mathrm{Ra-226}}}{A_1}(1-\varepsilon) + \frac{C_{\mathrm{Ra-226}}}{A_2}\varepsilon + \frac{C_{\mathrm{Th-232}}}{A_3} + \frac{C_{\mathrm{K-40}}}{A_4} \tag{4.7}$$

and the gamma activity concentration index $I_\gamma$

$$I_\gamma = \frac{C_{\mathrm{Ra-226}}}{A_1} + \frac{C_{\mathrm{Th-232}}}{A_3} + \frac{C_{\mathrm{K-40}}}{A_4} \tag{4.8}$$

As for the total index $I$ in Eq. (4.7), the first, third, and fourth terms account for the excess indoor gamma dose; the second term, for the radon inhalation dose. The first term takes into account the gamma dose reduction from the $^{226}$Ra chain due to emanation and exhalation of $^{222}$Rn. Indeed, radioactive equilibrium disturbance in the material, due to radon emanation, results in activity contents of $^{214}$Pb and $^{214}$Bi in the material lower than that of $^{226}$Ra.

$A_x$ values depend on the typical specific area $\rho d$ (kg m$^{-2}$) of building material, i.e., density multiplied by thickness.

The $A_x$ parameters are calculated assuming an excess dose of 0.3 mSv per year (dose criterion) above background, i.e., the typical levels of indoor exposure "which would be received in a room built from materials with typical activities." This dose criterion refers to the sum of gamma and radon exposure. Indeed, the building product must comply with both the total activity concentration index $I$ and the gamma activity concentration index $I_\gamma$, which have two different series of reference values, e.g., in the case of concrete, $I \leq 1$ and $I_\gamma \leq 0.4$.

In a similar way, the background dose accounts for both gamma radiation and radon and—like $I$ and $I_\gamma$ values—have been set for three classes of building products according to their density.

### 4.7.5 Austrian index

In Austria, the radioactivity in building material is regulated by the standard ÖNORM S5200 (Austrian Standard Institute, 2009). It is based on a similar index which, however, includes the exposure to Radon too:

$$I = \frac{C_{\mathrm{Ra-226}}}{880}(1 + 0.07\varepsilon\rho d) + \frac{C_{\mathrm{Th-232}}}{530} + \frac{C_{\mathrm{K-40}}}{8800} \leq 1 \tag{4.9}$$

with $\rho$ is the density in kg m$^{-3}$, $d$ is the thickness in $m$, and $\varepsilon$ is the radon emanation coefficient in the building material. If these values are not known than the default values that listed below have to be used:

$$d = 0.3\,m;\ \rho = 2000\,\mathrm{kg}\,m^{-3};\ \rho d = 600\,\mathrm{kg}\,m^{-2};\ \varepsilon = 0.1.$$

The formula (4.9) is based on a dose criterion of 1.0 mSv per year exceeding an annual outdoor background of 1.2 mSv.

In case of a nonequilibrium in the thorium decay chain it is accepted to use

$$C_{\mathrm{Th-232}} = 0.5(C_{\mathrm{Ra-228}} + C_{\mathrm{Th-228}}) \tag{4.10}$$

The simplified formula

$$I = \frac{\rho d}{250}\left[\frac{C_{\mathrm{Ra-226}}}{880}(1 + 18\varepsilon) + \frac{C_{\mathrm{Th-232}}}{530} + \frac{C_{\mathrm{K-40}}}{8800}\right] \leq 1 \tag{4.11}$$

can be used if the structural element has an areal density of below 250 kg m$^{-2}$.

When the index relation is fulfilled then the building material can be used without restriction. If the relation is not fulfilled then the (areal) weighted mean of all building materials of a room has to be used to check for compliance, however, the index of each contributing building material must stay below 2.

In addition, the surface β-activity must be below 2.0 Bq cm$^{-2}$. The measurement can be performed by a contamination monitor, which is calibrated for high-energy β-radiation.

### 4.7.6 Screening tool I(ρd)

Very recently a new tool to screen building materials as gamma ray source and accounting for density and thickness of building materials was published (Nuccetelli et al., 2015). Its structure is similar to the general expression (see Eq. 4.5) but terms $A_x$ are dependent on density and thickness.

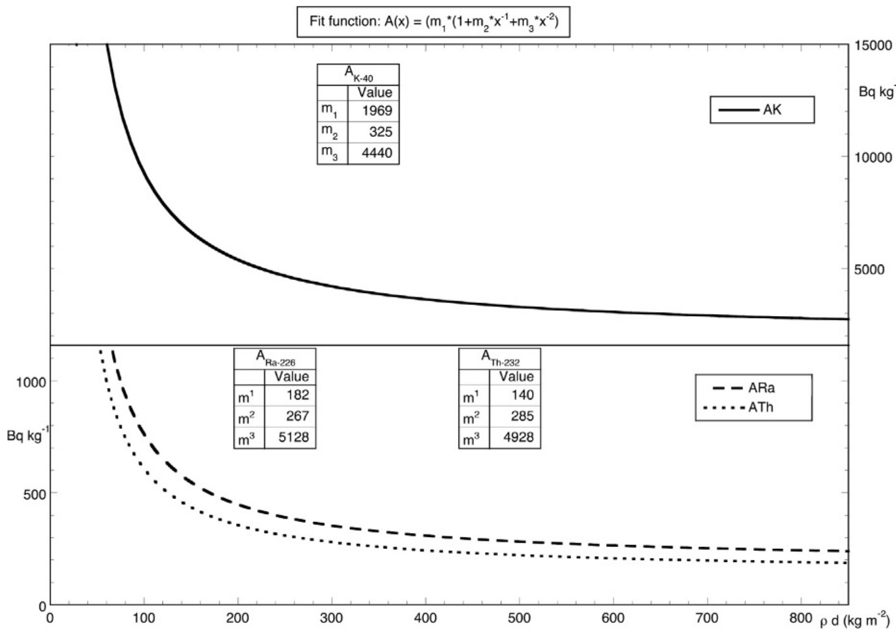


**Fig. 4.2** Graphics of the $A(\rho d)_x$ for Ra-226, Th-232, and K-40.
Modified from Nuccetelli, C., Leonardi, F., Trevisi, R., 2015. A new accurate and flexible index to assess the contribution of building materials to indoor gamma exposure. J. Environ. Radioact. 143, 70–75.

$$I = \frac{C_{\mathrm{Ra-226}}}{A(\rho d)_{\mathrm{Ra-226}}} + \frac{C_{\mathrm{Th-232}}}{A(\rho d)_{\mathrm{Th-232}}} + \frac{C_{\mathrm{K-40}}}{A(\rho d)_{\mathrm{K-40}}} \leq 1 \tag{4.12}$$

where the general expression of $A(\rho d)_x$ is

$$A(\rho d)_x = m_1 \left[ 1 + m_2 (\rho d)^{-1} + m_3 (\rho d)^{-2} \right] \tag{4.13}$$

It can be demonstrated that the $I_{\mathrm{BSS}}$ becomes a special application of Eq. (4.12). Indeed, when the factor ($\rho d$) equals 470 kg m$^{-2}$, the typical value for concrete used in RP 112 (EC, 1999), the rounded values of $A(\rho d)_x$ become 300, 200, and 3000 for Ra-226, Th-232, and K-40, respectively (Fig. 4.2). The coefficients $m_1$, $m_2$, and $m_3$ have different values for Ra-226, Th-232, and K-40 and it can be shown that the $m_1$ values in Eq. (4.9) represent the asymptotic behavior of the $A(\rho d)_x$ when $\rho d$ tends to infinity, i.e., the lower limits of the activity concentrations of Ra-226, Th-232, and K-40 determining 1 mSv per year from any kind of building material (see Nuccetelli et al., 2015).

The idea is not to replace the index of the Euratom Directive; however, since this is merely a conventional expression of the radioactivity content. The term “$I$” in the equation is rather like a function correcting for density and thickness in order to evaluate the dose for comparison with the reference level of 1 mSv per year.

## 4.8 Conclusions and recommendations

In the development of EU technical guidelines and national regulations increasingly building materials were recognized as an important source of indoor gamma exposure. In the new EU Basic Safety Standards (EU, 2014), for the first time, building materials were included in the scope of application.

This fact sets the need to control activity concentrations of selected natural building materials and of NORM-containing building materials to comply with the new EU reference level defined in terms of 1 mSv per year (as effective gamma dose). It is important to note that compliance to the Directive 2013/59/Euratom should be without prejudice to the provisions of Regulation (EU) No. 305/2011 about construction products and the consequent CE marking. Therefore, harmonization of EU procedures is required to support the free movement of building materials in the EU internal market. To achieve this goal, harmonized methods for the determination of the activity concentrations and the dose assessment are under development by the Technical Committee 351—WG3 of the European Committee for Standardization (CEN). These harmonized methods are especially needed for building materials with an index exceeding 1 where it is important to verify whether they comply with the reference level of 1 mSv per year.

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